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Study on Pillar Stability of Wongawilli Mining Area in Shallow Close Distance Coal Seams

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Abstract

In order to ensure the lower working face safety production under Wongawilli mining area pillars in shallow close distance coal seams in Bulianta coalmine, the influence of Wongawilli coal pillars' stability in upper coal seam on lower working face is studied by three-dimensional simulation and field measurement. The results of finite element software FLAC^{3D} shows that, the maximal vertical stress in Wongawilli coal pillars is 32 MPa, and the stress concentration factor is 4.8, but the pillars in Wongawilli mining area are stable. The results of on-site surface subsidence and rock pressure appearance shows that, the surface subsidence value corresponding to Wongawilli coal pillars is much less than old gob area, and the rock pressure appearance of mining face is always normal, so the result indicates that Wongawilli coal pillars are not unstable and the safety of extraction of 32301 working face is ensured. The research achievement would provide technique support for safety mining under similar condition in Shendong mining district.

Keywords: shallow; Wongawilli mining method; pillar stability; subsidence; strata behaviors; key stratum

Shendong mining district has always being paid attention to scientific mining and exploring actively by new mining technology and methods suitable for the distribution condition of coal seams in Shendong. Wongawilli mining method was introduced from Australia in the 1990s to solve the problem of mining bound and unstable coal seams by conventional mining methods^[1-5], and it improved the mining rate of difficult coal seams greatly. Based on the "room and pillar method", Wongawilli mining method is a new-style effective method combined with short wall and pillar. It has these features: continuous mining the coal seam with coal cutter; continuous transportation of the coal; roof management with entire caving; and the goaf supported by remaining pillars. The pillars in the Wongawilli mining area are mainly 0.5~0.9 m width for separating excavating roadways, and pillars with the width of 15~25m used to separate different areas are kept after several roadways are excavated with the purpose of supporting the coal roof effectively. However, when mining lower coal seam, especially when the mining height is high and the distance between two coal seams is very close, the stability of virgin coal in the upper coal seam would be affected. Sometimes it would cause dynamic load in the mining pressure probably with a hurricane and has a great effect on the safety of production^[6-10]. The working faces in the third panel of Bulianta coal mine during the

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initial stage are totally under the Wongawilli mining area, and whether the virgin coal in Wongawilli mining area of upper coal seam is stable or not can not be forecasted. Because of this, a thorough study on the stability of virgin coal in the Wongawilli mining area should be done when mining the first working face 32301 in the third panel.

1. Basic condition of the working face

Bulianta coalmine, which has a yearly capacity of 20.0 Mt, is one of the main mines in Shendong Corporation of Shenhua Group. working face 32301 is the first face of the third panel in 2² coal seam with a length of 301 m and an advancing distance of 5220 m. Its coal structure is simple, the angle of coal seam is 1~3°, and the thickness of aeolian sand in the unconsolidated layer is 5~20 m. The thickness of coal seam is 6.7~7.5 m with an average thickness of 7.1 m, and the average mining depth is 260 m. Fully-mechanized mining method is used with a whole cutting height at a time. The designed mining height is 6.1 m while the cutting supports are 6.3 m. Roof control method is entirely caving. The working face has a set of equipments as follows: ZT10800/28/55D style supports produced by Zhengzhou coal mining machinery Group Co.Ltd. with a rated working resistance of 10800kN, SL1000 Shearer produced by Eickhoff Corporation, and scraper conveyor by DBT Corporation.

Because longwall mining method and Wongawilli mining method are applied to upper 1² coal seam, 32301 working face is now located under three different areas, and along the head-to- tail direction of the conveyor, they are virgin coal area using Wongawilli mining method, solid virgin coal area and old goaf area. The 156 m range of 32301 working face away from the air return way is under the old goaf caused by 31301 longwall face in upper seam, while the 75 m range of 32301 working face away from the haulage drift is under Wongawilli mining area. The position relationship is shown in Fig.1 and the combined columnar section map of the third panel is shown in Fig.2.

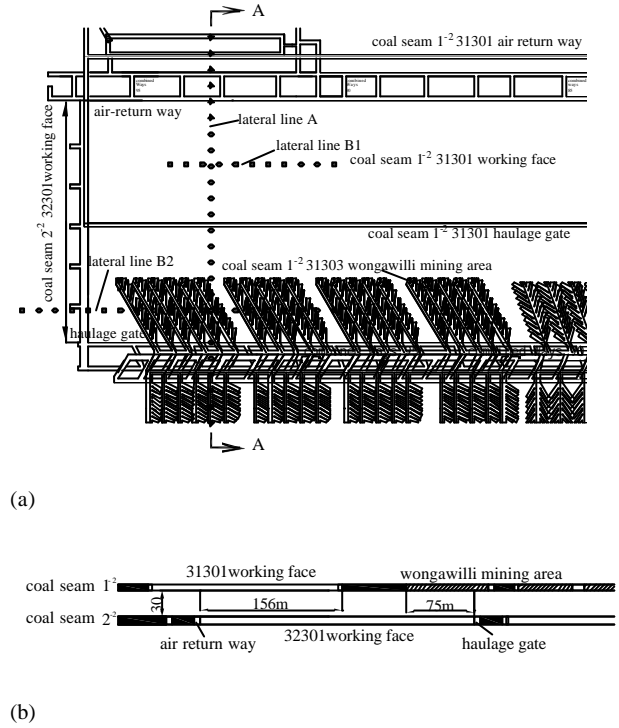


Fig. 1. Position relationship of 32301 working face (a) plan (b) section view of A-A

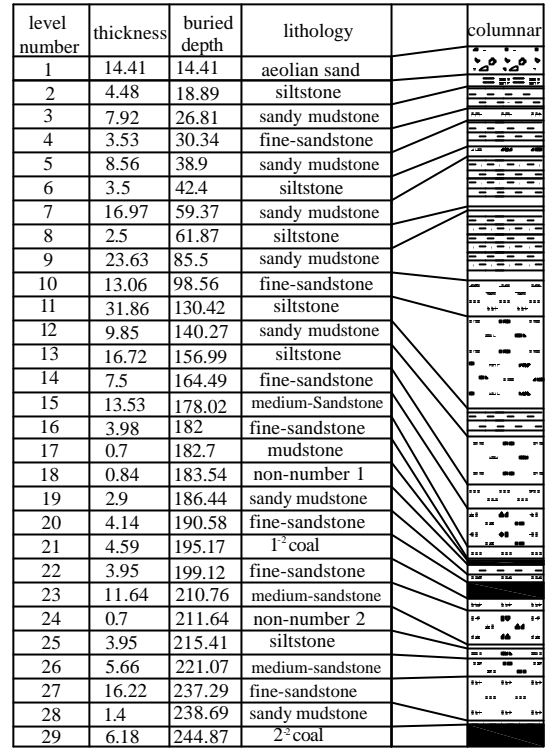


Fig. 2. Combined columnar section

2. Simulation of the stability of the Wongawilli coal pillar

2.1. Calculation Model and Simulation Program

• Calculation model

FLAC^{3D} has been widely used in the simulation of geological materials and geotechnical engineering with nonlinearity, large deformation and instability, especially the plastic flow of the materials reaching the yield limit and the gradual destruction together with caving of tracking materials. FLAC^{3D} modeling is based on the principle of the use of Mohr-Coulomb yield criterion to determine the damage of rock mass and reflect the strain-softening model, after the destruction of coal deformation with the development gradually reducing the residual strength of character. Based on the geological conditions and mining technology of the mining face, the level model is established (see Fig.3). The model's strike length is 1008 m, and inclined length is 615 m, and height is 137 m with a total of 361 148 units block and 406 375 grid nodes. The bottom and the side border in the model use displacement constraints, and the vertical loads are imposed on the top of model to simulate the weight of overlying strata.

According to the columnar section of working face shown in Fig.2 and combined with the scene of rock samples of various lithology of the physical and mechanical strength test results, the development of numerical simulation of the mechanical parameters of materials is shown in Table 1.

Table 1. Numerical simulation model of the mechanical parameters of rock

Lithology	Density	Bulk Modulus	Shear Modulus	Cohesion	Friction Angle	Tensile Strength
Sandy Mudstone	2300	8.33e9	3.85e9	3e7	34	6e6
Mudstone	2200	1.43e9	1.30e9	2e6	25	5e6
Siltstone	2350	1.11e9	8.33e9	8e6	35	8e6
Medium Sandstone	2500	2.28e9	1.84e9	1.5e7	38	9e6
Fine Sandstone	2500	2.78e9	2.08e9	2e7	40	1e7
Coal	1400	1.67e9	3.57e8	1e6	20	3e6

• Simulating mining process

According to actual mining situation to 2⁻² coal seam at field, we put forward a calculation scheme as below: firstly, mine longwall face and Wongawilli mining area in 1⁻² coal seams, then excavate the two crossheadings at working face 32301 in 2⁻² coal seam. At last, we calculate exploitation process of working face 32301. When mining the working face 32301, we make a excavating pace of 4m in the model. Every pace is calculated with 800 time-stepping.

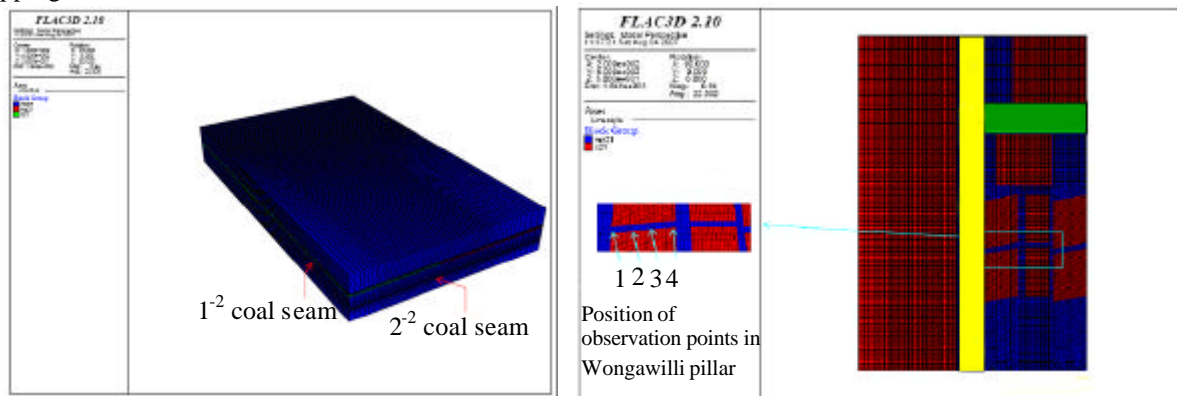


Fig. 3. Three-dimensional numerical simulation model diagram (a) model diagram (b) pillar survey line measuring point position

2.2. Simulation results and analysis

In the simulating mining process, extract vertical stress contour map at 2⁻² coal seam floor after every excavation (see Fig.4). The conclusion is: when the working face advances, there will appear stress increasing zone on both

sides of 32301 working face, especially above the Wongawilli mining area pillar, trend and strike direction pillar where would form large stress concentration.

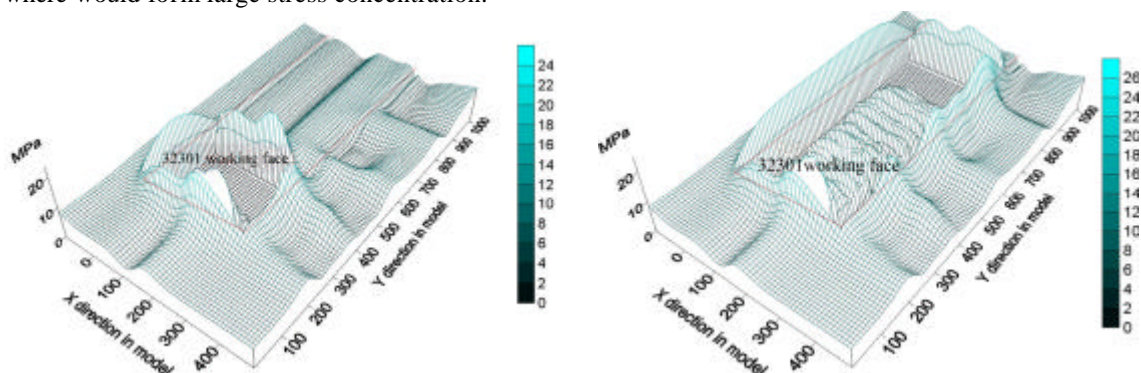


Fig. 4. Bottom plate vertical stress distribution map (a) 216 m (b) 648 m

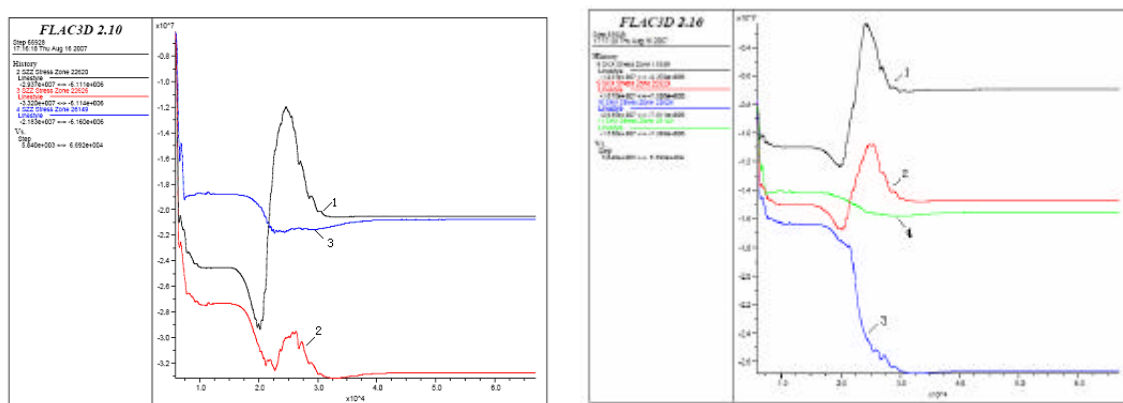


Fig. 5. The stress change curve drawing of monitoring point on Wongawilli pillar (a) vertical stress (b) horizontal stress with X direction

Fig.5 is the stress change curve of monitoring point in Wongawilli pillars. From it we can see that: when the working face excavates the coal pillars in Wongawilli mining area, the load of Wongawilli mining area experiences from small to large and then decreases. The bearing stress have larger change in a short time, the maximal vertical stress in Wongawilli coal pillars is 32 MPa, and the stress concentration factor is 4.8. The pillars in Wongawilli mining area are stable before excavating, even there is elastic rock body in the coal pillars of Wongawilli mining area. It shows that the roof destruction is not severe. During the mining of 32301 working face, the coal pillars in Wongawilli mining area are subjected to the tension and damaged, but the pillars are not unstable suddenly and prevent roof accident.

3. Practical measure research of Wongawilli coal pillar stability

3.1. Simulation results and analysis

• Observation Scheme of Surface Subsidence

According to daily observation of surface subsidence, we master remained pillars' stability of Wongawilli mining area indirectly. So, we dispose 3 surface observation lines between the upper coal seam of Wongawilli mining area and the long wall old goaf (see Fig.1). The total length of tendency observation line A is 500 m and the cutting whole distance is 150 m. The starting point is 100 m away from the working face 32301 and observation point spacing is 20 m, there are 26 observation points totally. The strike direction observation line B1 is 80 m away from the working face 32301 return way, namely the middle of 1² long wall coal old goaf. The total length of observation

line is 220m. The strike direction observation line B2 is 40 m away from haulage gate, namely the middle of 1⁻² coal in Wongawilli mining area, the total length of observation line is 500 m. All the observation point spacing is 20 m except that the control observation is 50 m.

- Observation scheme of strata behaviors

There are 176 stents at working face 32301, where 1~44# stents are under 1⁻² upside coal pillar of Wongawilli mining area and 85~176# stents are under 1⁻² upside coal long wall old goaf, PM31 system will real-time monitoring the stent support resistance when mining. It can be saved and reflected on the host computer screen. In addition, five julio cards are arranged on stents of 30[#], 62[#], 84[#], 126[#], and 156[#].

3.2. Result analysis of surface subsidence

When mining 32301 working face, we uses GTS -7001i total station to observe elevation and plane coordinate from August 4, 2007 to October 10, 2007, lasting for 68 days. During this time, the working face advanced from 126m to 752m, and was observed totally 25 times. The working face excavated about 10 m everyday from August 4, 2007 to August 24, 2007. We observed comprehensively everyday to master the upper coal pillars' stability in Wongawilli mining area at initial mining stage. Fig.6 is the tendency observation line of dynamic subsidence curve.

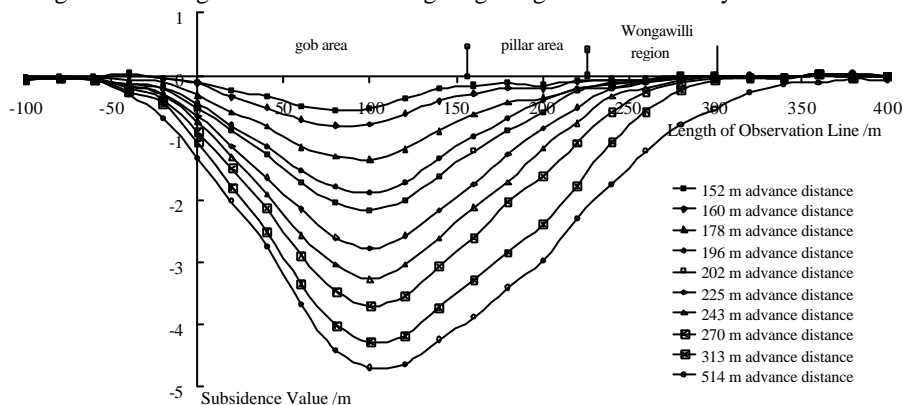


Fig. 6. The tendency observation line of dynamic subsidence curve

From Fig.6 we could know that on August 16, 2007 when the working face advanced 202 m, namely advanced 52 m from the tendency observation line, the surface subsidence corresponding to return way of working face 32301 was 0.514 m, and the maximum surface subsidence corresponding to 1⁻² coal long wall old goaf was 2.169 m. While, the surface subsidence corresponding to haulage gate of working face 32301 was 0.011 m, and the maximum surface subsidence corresponding to the Wongawilli mining area was 0.249 m. If lower coal was mined, it could lead to the instability of 1⁻² upper coal pillar in Wongawilli mining area. Working face 32301 was being mined as total under 1⁻² coal long wall old goaf, and its fitting subsidence curve was corresponding to the Fig.7. At this time, the surface subsidence corresponding to haulage gate of working face 32301 increased 0.503 m, and the surface subsidence corresponding to the place 75 m away from haulage gate of working face 32301 increased 1.797 m. On September 20, 2007, when the working face advanced 514 m, namely advanced the the tendency observation line 364 m, the regional overlying strata movement and surface subsidence corresponding to its tendency observation line had become steady. Working face 32301 return way's surface subsidence was 1.324 m, the maximum surface subsidence corresponding to 1⁻² coal long wall old goaf was 2.038 m. While, the surface subsidence corresponding to haulage gate of working face 32301 was 0.546 m, and the maximum surface subsidence corresponding to the total Wongawilli mining area was 2.038 m. If mining the lower coal could lead to the instability of 1⁻² upper coal pillar in Wongawilli mining area. From the fitting subsidence curve in Fig.7, we could see that the surface subsidence Corresponding to haulage gate of 32301 working face should be increased 0.778 m, and the surface subsidence corresponding to the place 75 m away from haulage gate of working face 32301 should be increased 2.097 m.

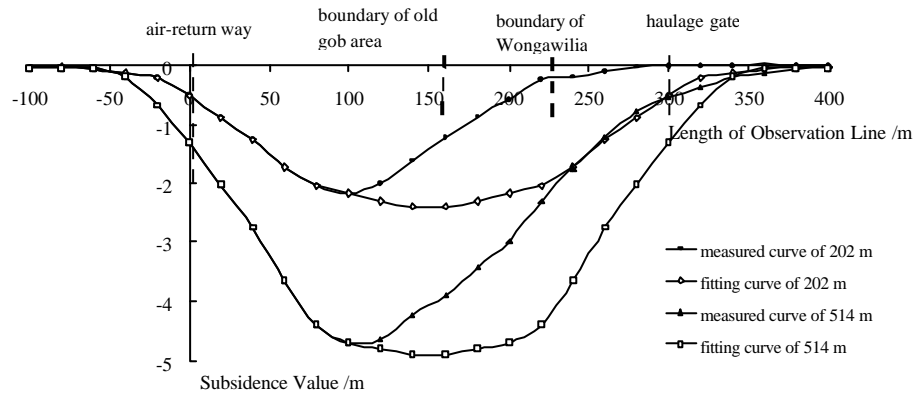


Fig. 7. The tendency observation line fitting subsidence curve

According to the analysis mentioned above, considering the surface subsidence characteristics in shallow close distance coal seams during first mining on ShenDong mining district, we could obtain that the Wongawilli coal pillars in 1^{-2} coal seam are not unstable; if Wongawilli coal pillars have instability, the tendency observation line fitting subsidence curve should be similar to the fitting subsidence curve in Fig.7. In fact, pillars in Wongawilli mining area corresponding to the surface subsidence is much smaller than the fitting subsidence curving. It indicated that Wongawilli mining area and its upside rock mass global motion are stable. Mining area corresponding to the surface did not have clearly sidestepped and cracked. It shows that pillar in 32301 working face in mined mining area is stable. This is also proved by field strata behaviors. During the 32301 working face was advancing, it did not have roof fall, impulsion pressure, hurricane and others for upside coal legacy pillar instability.

3.3. Results analysis of strata control observation

Fig.8 shows for the working resistance curve of No.30 hydraulic support under coal pillar in Wongawilli mining area, from Fig.5 we can see, during initial stage of production for the mining face 32301, support resistance under Wongawilli mining area pillar is relatively small, and almost less than 9800 KN in all. Compared with the mining under old upper coal goaf, mining under the Wongawilli pillar area is similar to the initial single-seam mining. Therefore, first weighting interval and periodic weighting length under the Wongawilli mining area exceeded those under the old mined-out area. When the working face had advanced to 32 ~ 35 m, because of the region corresponding to the old goaf area appeared initial pressure on the activation of the 1^{-2} top coal breaking layer structure of a key block, it led to the ground level boundary cracks appearance in the old mined-out area under the mining-induced rock movement which had passed to the surface. However, the initial pressure appeared when virgin coal was advanced to 41m in Wongawilli mining area, but there was no minor mining cracks branch before advanced a distance of 165 m. During this time, the leader of Shendong Bulianta mine attached great importance to the initial pressure due to first break of the main key siltstone stratum which is 31.86 m above the virgin coal of Wongawilli coal mining area because the initial pressure could lead to large-scale instability of the virgin coal. At the same time, a series of preventive measures were taken to strengthen the pillar. When the mining face advanced to 170 m, significant ground subsidence appeared because the main key stratum of virgin coal in Wongawilli coal mining area had been broken. At this time, the working resistance of the supports in the working face reached the rated 10800 KN, however, the stent contracted about only 20 ~ 30mm due to the under pressure. The ground behavior of mining face was normal with no fall roof caving or breaker props, so we could declare that virgin coal in Wongawilli mining area was not unstable.



Fig. 8. Working resistance curve of No.30 hydraulic support under wongawilli mining area pillar

4. Conclusion

The results of three-dimensional finite simulation show that, after working face 32301 is mined, the maximum compressive stress in pillars of Wongawili mining area is 32MPa, and the stress concentration factor can reach 4.8, but it reaches 50% in elastic core region. Simulation results show that the pillar of Wongawili mining area is not unstable during the mining process.

The results of surface subsidence measurement show that: the surface subsidence corresponding to the haulage gate of working face 32301 under the pillar of Wongawili mining area and the maximal surface subsidence corresponding to the whole Wongawili mining area are only 0.546 m and 2.308 m respectively, which are much less than 1.324 m and 4.701 m when the pillars in Wongawili mining area is unstable, so the measured results show that the pillar of Wongawili mining area is stable.

The monitoring results of the strata behaviors show that the overlying strata movement of the area corresponding to old goaf of upper coal seam has already delivered to the ground when working face 32301 advances to 32~35 m. But the key stratum first break when the working face advances to 170 m. During the first weighting in working face, the piston contracts 20~30 mm with the normal appearance of coal pressure, and the results show that the pillars of Wongawili mining area is stable.

Acknowledgements

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References

- [1] X. M. Song, Theory forecast of hurricane disaster and disaster-prevention project design in working mine. *Journal of Taiyun University of Technology*, 37 (2006) 35-37.
- [2] L. G. Wang, X. X. Miao, Study on catastrophe characteristics of the destabilization of coal pillars. *Journal of China University of Mining & Technology*, 36 (2007) 7-11.
- [3] S. J. Chen, W. J. Guo, Y. J. Yang, Research on stability of strip coal pillar based on laboratory test. *Rock and Soil Mechanics*, 29 (2008) 2678-2682.
- [4] X. Z. Peng, X. M. Cu, J. C. Wang, Stability analysis of irregular coal pillars based on voronoi diagram. *Journal of China Coal Society*, 33 (2008) 966-970.
- [5] J. H. Xu, X. X. Miao, X. C. Zhang, Analysis of the time-dependence of the coal pillar stability. *Journal of China Coal Society*, 30 (2005) 433-437.
- [6] W. B. Zhu, J. L. Xu, X. S. Shi, Research on influence of overburden primary key stratum movement on surface subsidence with in-situ drilling test. *Chinese Journal of Rock Mechanics and Engineering*, 28 (2009) 403-409.
- [7] M.D.G. Salamon, Stability, instability and design of pillar workings. *International Journal of Rock Mechanics and Mining Science & Geomechanics Abstracts*, 7 (1970) 613-631.
- [8] H. Bogert, S.J. Jung, H.W. Lim, Room and pillar stope design in highly fractured area. *International Journal of Rock Mechanics and Mining Sciences*, 34 (1997) 145.e1-145.e14.

- [9] R. Singh, P. R. Sheorey, D. P. Singh, Stability of the parting between coal pillar workings in level contiguous seams. *International Journal of Rock Mechanics and Mining Sciences*, 39 (2002) 9-39.
- [10] K. G. Liu, J. C. Wang, J. H. Xu, Study on mining system and stability of coal pillar in short-wall mechanized mining. *Journal of China University of Mining & Technology*, 34 (2005) 24-29.